Radiation Mapping UAV

COMPUTER SCIENCE COLLEGE OF ENGINEERING UIC

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Fermilab

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Abstract

The NuMI (Neutrinos at the Main Injector) target system delivers a high-energy flux of muon-neutrinos towards a detector more than 800 km away with the goal of better understanding the origin of the universe and its evolution. The target system becomes radioactive because it is irradiated by a sub-Mega-Watt power proton beam. Radiological hazard is one of critical issues for a radiological worker which limits their activities near the target system; however, they often need to quantify the radiation level of the target system manually. Thus, the objective of this project is to reduce their exposure to radiation while improving the accuracy of the measurements. A quadcopter UAV fitted with a radiation dosimeter is ideal to traverse the irradiated environment as it can be deployed in any space and requires minimal hardware integration to the test room. Due to the lack of indoor GPS signal, this UAV utilizes a series of ultrasonic beacons that release several varied-frequency pulses simultaneously in order to localize the UAV. The flight controller returns a 3D coordinate tied to the radiation data to understand precisely where radiation spikes are being emitted from the horn. The flight controller stores log data that can be processed into an easily interpretable map of radiation intensities. The radiation map serves as one of the primary references for planning the transportation of the NuMI horn.

Project Objectives

The objective of this project is to mitigate worker exposure to radiation while improving the accuracy of the radiation measurements. To reach this objective, multiple acceptance criteria have been outlined which must be met. The acceptance criteria are as follows:

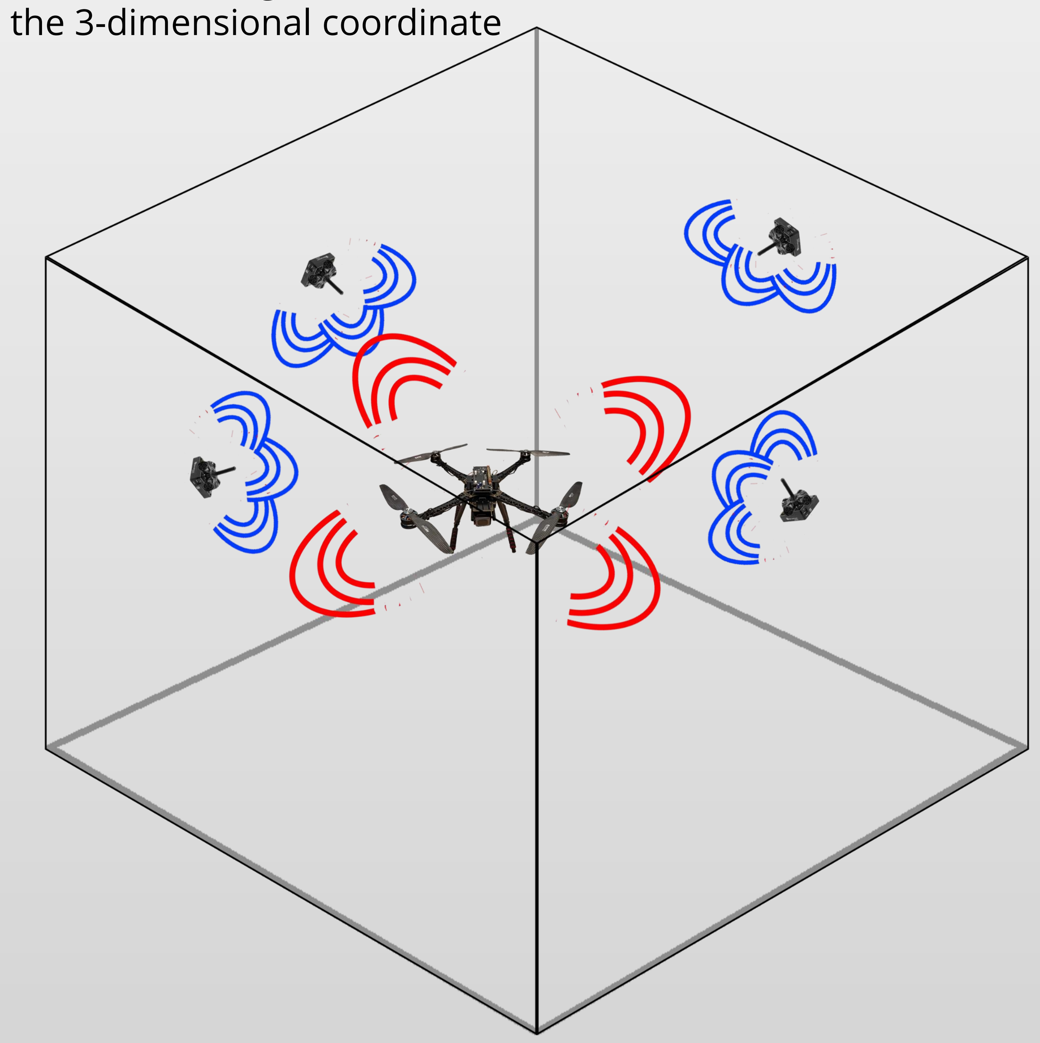
- The UAV must be manually controllable by an operator
- Real-time video stream is available for remotely operating the UAV
- Software to process data into a two-dimensional intensity map that visualizes radiation/temperature intensities
- Temperature will be scanned in a room for testing purposes since program development will be difficult for radiation detection outside of the Fermilab facility

Final Design

Indoor Positioning

Indoor positioning is a modern challenge with growing demand for a solution. A GPS signal already struggles to reach indoors and will undoubtedly fail to reach this testing facility. To localize the UAV in the indoor environment, the Marvelmind Indoor Navigation System is integrated onto the UAV.

- One mobile hedgehog beacon is integrated to the underside of the UAV which releases multiple ultrasonic pulses
- Four stationary beacons are placed around the room which receive ultrasonic pulses
- Beacons communicate to the base station over radio frequency (RF)
- Propagation delay is used to calculate the distance between the mobile beacons and each stationary beacon
- Trilateration algorithm with an Extended Kalman filter calculates the 3-dimensional coordinate



Flight Controller

The flight controller (FC) is commonly called the "brains" of the UAV. A simple FC receives and processes signals from the radio receiver and directs the corresponding power to each propeller motor. The Pixhawk 4 FC was selected for this application due to its robustness. The Pixhawk is equipped with two processors, an accelerometer and gyroscope for flight correction, servo outputs, and telemetry capabilities. Through the companion software, fail-safes and flight planning can also be programmed into the design.

Flight Modes

- Alt Hold – The vertical position of the UAV is held constant using the onboard barometer while allowing lateral movement

Fail-safes

- Automated land mode – The UAV makes a controlled descent to the ground when
  - Battery falls below 15% charge
  - Controller signal is lost
- Emergency Motor Shutoff – Power to motors is cut when the emergency cut off switch is triggered by the operator

Methodology

Several UAV builds have been considered during the initial design process. The three most viable options were compared with a decision matrix. The S500 Quadcopter build scored highest in the decision matrix due to its lower weight and longer flight time when compared to the S550 Hexacopter.

		S500 Quadcopter	Lynxmotion Quadcopter	S550Hexacopter
Criteria	Weighting Factor	Score (1-5)		
Thrust:Weight Ratio	0.3	5	3	5
Motor Efficiency	0.2	4	3	5
Flight Time	0.25	5	3	4
Total Weight	0.15	4	5	3
Cost	0.1	4	4	4
	Weighted Score:	4.55	3.4	4.35

Criteria	Definition	Rating
Thrust:Weight Ratio	Ratio of thrust generated to weight of UAV	<1.5: 1-2 1.5-2: 3 >2: 4-5
Motor Efficiency	Efficiency of motors at hovering operation	<80%: 1-2 80-85%: 3 >85%: 4-5
Flight Time	Length of time the UAV can sustain flight on one battery charge	<10 Minutes: 1-2 10-12 Minutes: 3 12-15 Minutes: 4 >15 Minutes: 5
Total Weight	Weight of all UAV components and accessories	>2500g : 1 2000g-2500g: 2-3 1500g-2000g: 4 1000g-1500g: 5
Cost	Total cost of the UAV	>$2000 : 1 $1500-$2000: 2-3 $1000-$1500: 4 <$1000:5

A number of indoor positioning methods have been explored; they include RF, LIDAR, UWB, optical, and ultrasonics. The ultrasonic trilateration method scored higher by a small margin.

		Pozyx UWB	Ultrasonic Kit	Grid Mapping	QR Code
Criteria	Weight	Score (1-5)			
Accuracy	0.3	3	4	4	1
# of Dimensions	0.05	5	5	5	3
Refresh Rate	0.1	5	2	3	5
On-Board Weight	0.25	5	5	3	5
Cost	0.05	3	4	5	5
Complexity	0.1	3	3	3	4
Scalability	0.15	4	4	5	1
Weighted Score		3.95	4	3.8	3

Criteria	Definition	Rating
Accuracy	Deviations from the true position of the UAV Acceptance criteria from Fermilab: +/- 10 cm	Below acceptance criteria: 1-2 Meets acceptance criteria of 10cm : 3 Exceeds acceptance criteria: 4-5
# of Dimensions	The number of dimensions in position the data acquires	1D: 1 2D: 3 3D: 5
Refresh Rate	Number of data points acquired per second. Refresh rate of 30Hz is ample. Very high sample rates will likely be down sampled	<30 Hz: 1-2 30 Hz: 3 >30 Hz: 4-5
On-Board Weight	Weight of the sensors/equipment that will be added to the UAVs payload, separate from essential UAV components.	>500g : 1 250g-499g: 3 <250g: 4-5
Cost	Cost of entire IPS/Localization equipment	>$1000 : 1-2 $500-$999: 3 <$500 : 4-5
Complexity in Design	Software Provided vs. Original Code Hardware Setup Level of Assembly/Manufacturing Required"	Subjective scale: 1-5
Scalability	What needs to be changed when room is changed or object being measured changes	Software and Hardware: 1 Software only: 3 Hardware only: 4 Nothing at all: 5

UAV Features

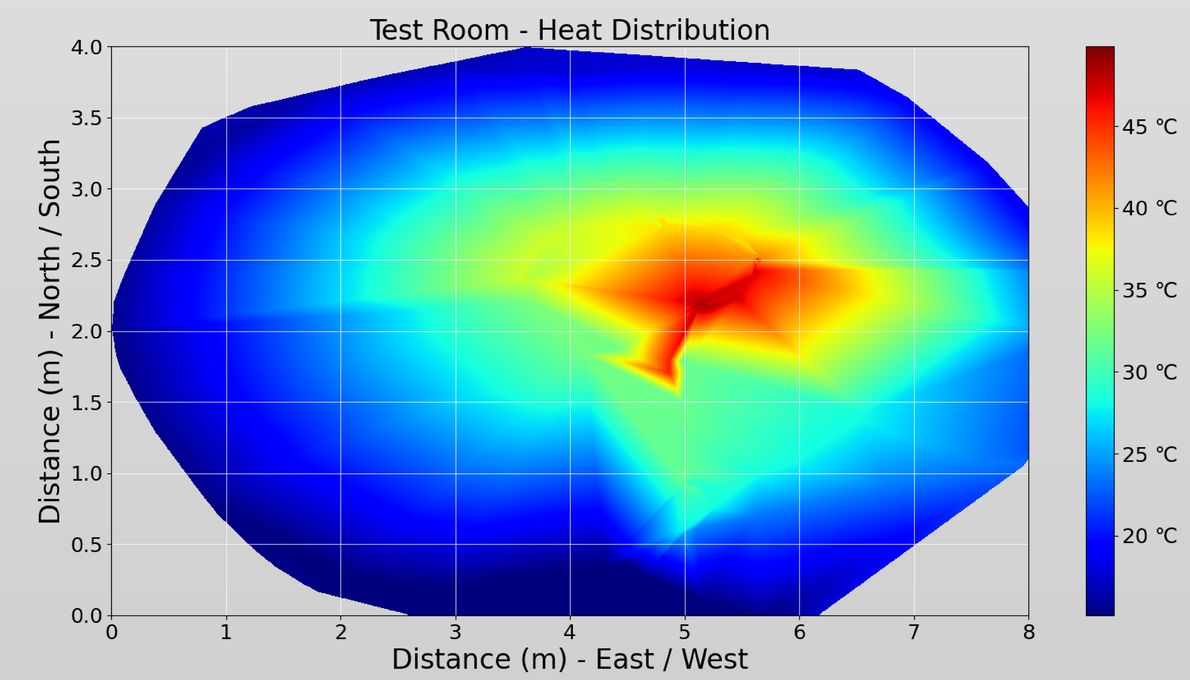
- Additional carrying capacity of 1kg
- Front facing camera with live video
- Utilizes off-the-shelf components for easy repair/replacement
- Automated land mode
- Altitude hold flight mode
- Wireless data transfer
- Low battery fail-safe
- Radio signal loss fail-safe
- Emergency shutoff switch in radio controller

The UAV's performance characteristics are outlined in the table below. The main highlights are the very strong thrust-to-weight ratio of 3.1:1 along with its 22 minute flight time.

Thrust:Weight Ratio	Motor Optimum Efficiency (%)	Flight Time (min)	Total Weight (g)	Additional Payload Capacity (g)	Electrical Power at Max Thrust (W)
3.1:1	89.9%	22	1700	1000	293

Mapping Software

A companion program has been built using Python to process the UAV's flight and temperature logs. This program imports the log files and uses an algorithm to scale latitude/longitude coordinates to meters away from the minimum latitude and longitude. This generates a map representing the area of the room that the drone flew in. It then uses linear interpolation to produce a two-dimensional temperature distribution on a plane of constant altitude. The X and Y axis are the metric location in the room and the color corresponds to the intensity of the recorded radiation/temperature measurement. When viewing this map on a computer, the user's cursor can be hovered at any desired area of the map and shows the exact coordinate as well as the temperature in °C.



Future Work

The team has achieved great success in developing a proof of concept UAV to map temperature. For further improvements of the system, we would like to implement a live updating map as the drone is scanning, autonomous flight plans for semi-autonomous scanning, and adding additional beacons for greater positional accuracy.

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